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MAGNETIC EMISSIONS TESTING OF THE SPACE STATION ENGINEERING MODEL RESISTOJET

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SUMMARY

The engineering model resistojet intended for altitude maintenance onboard the Space Station was tested for magnetic radiation emissions in the Radio Frequency Interference (RFI) facility at the Goddard Space Flight Center. The resistojet heater was supplied with power at 20 kHz and low voltage through a power controller. The resistojet was isolated from its power supply in the RFI enclosure, and the magnetic emission measured at three locations around the resistojet at various heater currents. At a heater current of 18.5 A the maximum magnetic emission was 61 dB_{Pt} at a distance of 1 m from the resistojet and at a location at the rear of the thruster. Calculations indicate that the case and heat shields provided a minimum of 4 dB of attenuation at a current of 18.5 A. Maximum radiation was measured at the rear of the resistojet along its major axis and was thought to be due to the magnetic radiation from the power leads. At a distance of 37 cm from the resistojet the maximum magnetic radiation measured was 73 dB_{Pt} at a current of 11.2 A. The power input leads were also a source of magnetic radiation. A steel pipe was able to attenuate up to 2 dB of radiation coming from the input leads. The engineering model resistojet requires about 20 dB of additional shielding in order to meet the Space Station specification for magnetic radiation.

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INTRODUCTION

The engineering model resistojet (fig. 1) intended for altitude maintenance onboard the Space Station contains a resistance heater element which is intended to raise the propellant gas temperature to a range of 1200 to 1400 °C. The resistance element consists of a platinum wire surrounded by a magnesium oxide insulator enclosed within a platinum - 10 percent rhodium sheath. It was desirable to have the heater leads terminate at the rear of the thruster (fig. 2). This design requirement dictated a heater design which starts with a single loop of heater material. This loop is then wound around a mandrel in an efficient heat transfer design. Figure 3 shows a layout drawing of the heater coil as it appears after it is wound around the mandrel. In the upper right and in the lower portion of the figure note that there is a loop of heater material with a radius of about 1.3 cm which acts as a strain relief. This loop has a radius into which the heater coaxial assembly can be safely bent without danger of cracking due to high stresses. The loop is required since the heater electrical terminations are made outside the thruster in a low temperature environment. This loop becomes a source of magnetic radiation when the heater is activated by an ac power supply. The area enclosed by the leads bringing power to the resistojet also radiates a magnetic field because there is a small area uncompensated by current moving in opposite directions. This area could be minimized by a suitable design.

ANALYSIS

The formula for magnetic field strength for a single coil of wire in air may be simplified to

$$B = \frac{2ia}{10r^3}$$

where B is the magnetic field strength in gauss, i is the current flowing through the wire in amperes, a is the area of the coil given in square centimeters, r is the radial distance (in centimeters) at which the magnetic field is to be measured.

The area of the loop is calculated to be 3.55 cm^2 . If one assumes a resistojet current of 22 A (a typical operating condition) and a distance of 7 cm, then the magnetic field strength is

$$B = \frac{2(22)(3.55)}{10(7)^3} = 4.55 \times 10^{-2} \text{ G}$$

Converting to picotesla results in

$$4.55 \times 10^{-2} \text{ G} \left(\frac{1 \text{ T}}{10^4 \text{ G}} \right) \left(\frac{10^{12} \text{ pT}}{1 \text{ T}} \right) = 4.55 \times 10^6 \text{ pT}$$

Converting to dBpt (dB above 1 pT) yields

$$\text{dBpt} = 20 \log 10^6 + 20 \log 4.55 = 133 \text{ dBpt}$$

Reference 1 specifies that, for the Space Station, the magnetic field at a distance of 7 cm from the equipment and at a frequency of 20 kHz is 100 dBpt. Thus the heater emits magnetic radiation in excess of the Space Station specification. The previous calculation, however, ignores any shielding due to the resistojet thermal insulation and case. Because of the uncertainty of these shielding effects and because an actual measurement was desired, it was decided to make a series of magnetic emission tests at the test facility of the Goddard Space Flight Center since the equipment is not available at the NASA Lewis Research Center.

Apparatus

Engineering model resistojet serial number 3 was used for the tests. Power was supplied by a variable frequency power supply operated at 20 kHz. The power controller, developed by the Auxiliary Propulsion Branch of NASA Lewis (ref. 2), was used to supply low voltage power to the resistojet. This simple, efficient controller is composed of a current limiting transformer and a power factor correction capacitor. The transformer limits initial cold-start current surges and maintains nearly constant power over the full operating resistance range of the thruster heater. Figure 4 shows a schematic of the equipment and the measuring instrumentation. The parameter measured at each test point included power supply frequency, power supply output volts, power controller output volts, power controller output current, power supply output

power, power controller output power, magnetic radiation in dBpt, and power controller, output phase angle. The resistojet heater resistance was calculated at each test condition to make sure it remained well below $0.9\ \Omega$. A resistance value of $0.9\ \Omega$ was considered safe since it corresponds to a heat exchanger temperature of $1200\ ^\circ\text{C}$. Power was supplied to the resistojet with a coaxial cable that measured 1.2 m in length. This cable length was minimized in order to minimize capacitance in the heater circuit. The resistojet had external leads of braided number 10 wire about 20 cm long which were twisted and attached to the coaxial cable. This cable went into the screen room through a bulkhead tube. The power supply, measuring instrumentation, and power controller were located outside the screen room where the magnetic emissions were measured. Figure 5 shows the equipment layout and the locations where the magnetic radiation was to be measured. Reference 3 specifies how the magnetic emissions were measured.

PROCEDURE

The testing was done in four phases. In the first phase of the testing, magnetic emissions were measured at the distance of 1 m at both the left and right side and at the rear of the resistojet. At each position the pickup coil was initially placed at a distance of 1 m perpendicular to the axis of the resistojet. Magnetic emissions were measured and recorded. The pickup coil was then placed parallel to the axis of the resistojet (at the same location) and the emission measured and recorded. It was thus determined at which position the higher emission was obtained. The coil was placed in this position, and the emissions were measured at heater currents of 5.6, 11.2, 16.8, and 18.5 A. Emissions were measured at a distance of 1 m because of limitations in the placement of the pickup coil.

In the second phase of the testing, the magnetic radiation was measured with an uncalibrated probe at a distance of 1 m over a hemisphere above the resistojet. An uncalibrated probe was used because of its small size (10 cm) and portability. The purpose of this sweep test was to determine qualitatively where the magnetic field was a maximum.

The third phase of the testing was intended to measure the magnetic radiation at a distance of 7 cm. The reason for this test is that reference 1 specifies magnetic radiation measured at this distance. Because the pickup probe has a diameter of about 2 ft, the closest the probe was capable of being placed to the resistojet was about 37 cm.

The fourth and final phase of the testing was intended to determine the effect of shielding the power input leads to the resistojet. This was done because there was concern about the magnetic radiation emitted by the power input leads. For this reason the power input leads were shielded with a 6.4-cm-diameter schedule 40 steel pipe with a wall thickness of approximately 0.5 cm. This pipe provided a conveniently available shielding material. Magnetic radiation emissions were measured on the left and on the right side of the resistojet at the heater current of 11.2 A with the shield in place.

RESULTS AND DISCUSSION

Results of first phase of the testing are tabulated in table I. As expected, the magnetic radiation is a direct function of the resistojet heater current. Magnetic radiation ranged from a low of 46 dBpt at a heater current of 5.6 A to a high of 61 dBpt at a heater current of 18.5 A. At a given current, the highest magnetic radiation was usually measured at the rear of the resistojet. This was thought to be caused by radiation from the heater power input leads at the rear of the resistojet. The exception was at a heater current of 5.6 A where the maximum radiation was measured on the right side of the resistojet. At a heater current of 18.5 A the calculated magnetic radiation is 62 dBpt, neglecting any shielding affects. If for the moment the data point taken at the rear of the resistojet is ignored, there was measured a maximum of 58 dBpt at a current of 18.5 A. This indicates that a minimum of approximately 4 dB of magnetic radiation has been shielded by the resistojet heat shields and case at 18.5 A of heater current. Figure 6 is a plot of magnetic emission as a function of heater current with position as a parameter. Figure 6 also shows the theoretical emission curve. This plot further illustrates that magnetic emission is a direct function of heater current and that the maximum emissions were generally measured at the rear of the thruster. The unsymmetrical nature of the emissions is thought to be due to a combination of radiation from the thruster power input leads and the placement of the heater strain relief loop. Under actual flight conditions slight variations in this shielding value are possible depending on the equilibrium temperature of the case and shield. The equilibrium temperature of these parts in a vacuum space environment is probably lower than the levels reached in this test made at ambient pressure.

The second part of the testing was intended to determine where maximum radiation occurred when a sweep was made over a hemisphere above the resistojet. For this test a small uncalibrated probe swept over the hemisphere above the resistojet while the emission value was called out from the control room. The heater current was maintained at about 11.2 A for this test. This test indicated that the maximum emissions were at the rear of the resistojet along its major axis.

This test thus confirmed the results obtained in the first phase of testing. The radiation from the heater leads is due to their configuration for this test. Approximately 25 cm of twin wire leads were exposed at the rear of the resistojet. These leads were twisted and connected to a coaxial cable about 1 m in length which fed power to the resistojet from the power controller located outside the screen room. This lead configuration was far from ideal and no doubt had areas where the current was uncompensated by current going in the opposite direction thus giving rise to spurious magnetic radiation.

The next test was intended to determine the magnetic radiation at a distance of 7 cm. As previously noted, the closest the pickup coil was capable of being placed to the resistojet was about 37 cm. The heater current used for this test was 11.2 A. The radiation measured was 71 dBpt on the left side and 73 dBpt on the right side. Calculations indicate that the maximum magnetic radiation at a distance of 37 cm is approximately 86 dBpt neglecting shielding effects for the heat shields and resistojet case. Figure 7 is a plot of magnetic emissions as a function of distance from the resistojet. The upper curve is the theoretical emissions calculated with the assumption of no shielding. Extrapolating the upper curve to 7 cm yields a value of 104 dBpt. The magnetic

emissions are reduced to zero at a distance of 9 m. There is a rapid drop off in magnetic radiation beyond a distance of 1 m because of the inverse cubic relationship between magnetic radiation and distance. This plot illustrates that the effect of shielding is greater at a distance of 37 cm than at a distance of 1 m.

The last phase of the testing was an attempt to quantify the effects of radiation from the resistojet power input leads. The power input leads were shielded with a 6-cm diameter schedule 40 steel pipe having a wall thickness of approximately 0.5 cm. With this shield in place and with a heater current of about 11.2 A, the magnetic radiation was measured at a distance of 1 m. The results were 53 dBpt on the right side of the resistojet and 49 dBpt on the left side. These numbers compare to 54 dBpt on the right side and 51 dBpt on the left side, both of which were obtained without the lead shield in place. Thus the pipe was able to shield up to 2 dB of radiation coming from the input leads.

COMMENTS AND RECOMMENDATION

JSC 30237, Space Station Electromagnetic Ionizing Radiation and Plasma Environment Definition and Design Requirements, specifies that the magnetic field limit at a distance of 7 cm at a frequency of 20 kHz is 110 dBpt. This is a very stringent specification. For example, the earth's magnetic field is about 150 dBpt. Figures 6 and 7 may be used to estimate the radiation at a distance of 7 cm and a current of 22 A. Figure 7 indicates that at a current of 11.2 A the magnetic radiation at a distance of 7 cm is 104 dBpt. Figure 6 indicates that an increase in current from 11.2 to 22 A results in an increase in emission of about 10 dB. Therefore, the radiation at a distance of 7 cm is 114 dBpt at a current of 22A. In order to meet the 110 dBpt limit, $114 - 110 = 4$ dB of shielding would have to be provided.

Based on this preliminary test, it is recommended that a magnetic radiation shield for the resistojet assembly be designed. This shield would need to provide about 4 dB of attenuation and could be combined with the micrometeroid shield which is also required with the assembly.

REFERENCES

1. Space Station Electromagnetic Emissions and Susceptibility Requirements for EMC. MIL-STD-461B amended, NASA Johnson Space Center, JSC30237, November 4, 1986.
2. Gruber, Robert P.: Resistojet Control and Power for High Frequency of ac Buses. NASA TM-89860, 1987.
3. Electromagnetic Interference Characteristics, Measurement of. MIL-STD-461 (MI), Dept. of Defense, July 31, 1987.

TABLE I. - RESULTS FROM PHASE 1 OF THE TESTING

Position	Current, A	Magnetic radiation, dB above 1 pT
Left side	5.6	46
	11.2	51
	16.8	56
	18.5	57
Right side	5.6	47
	11.2	54
	16.8	57
	18.5	58
Rear	5.6	46
	11.2	56
	16.8	61
	18.5	61

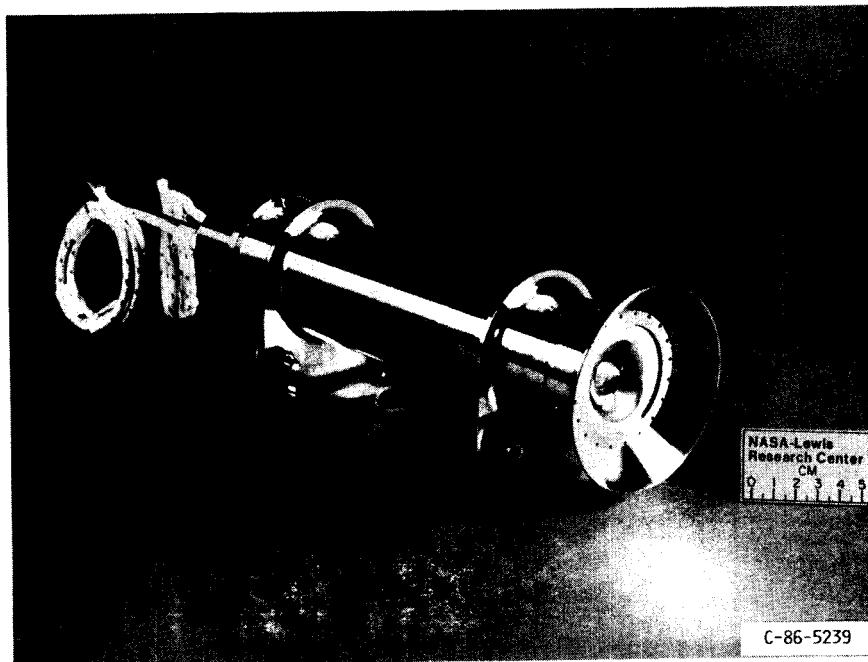


FIGURE 1. - ENGINEERING MODEL OF RESISTOJET.

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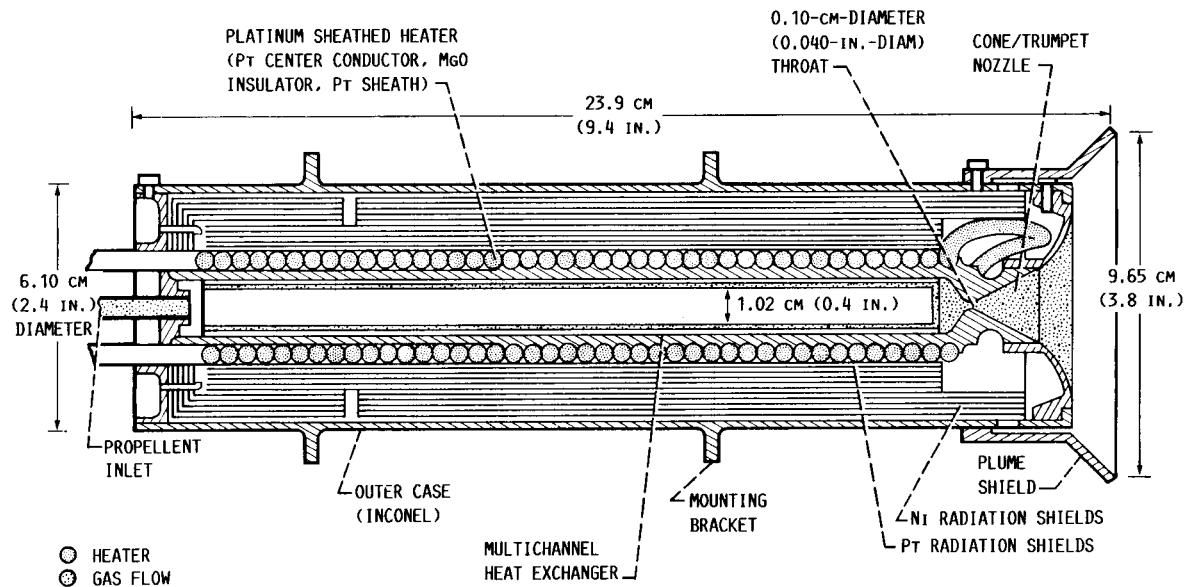


FIGURE 2. - ADVANCED DEVELOPMENT ENGINEERING MODEL RESISTOJET.

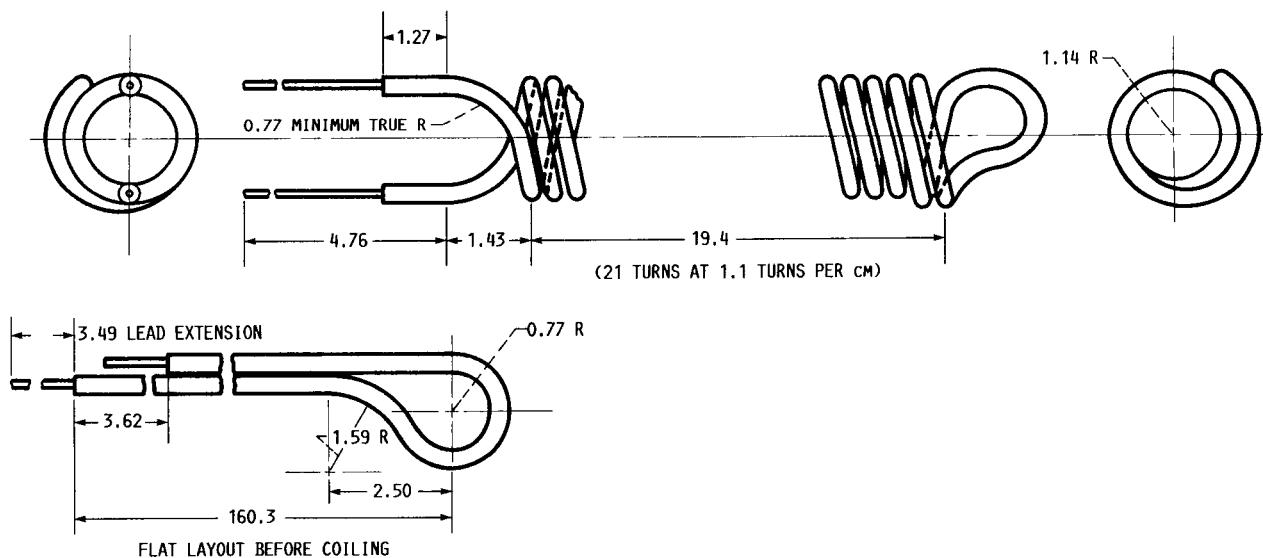


FIGURE 3. - RESISTOJET HEATER COIL. (ALL DIMENSIONS IN CM.)

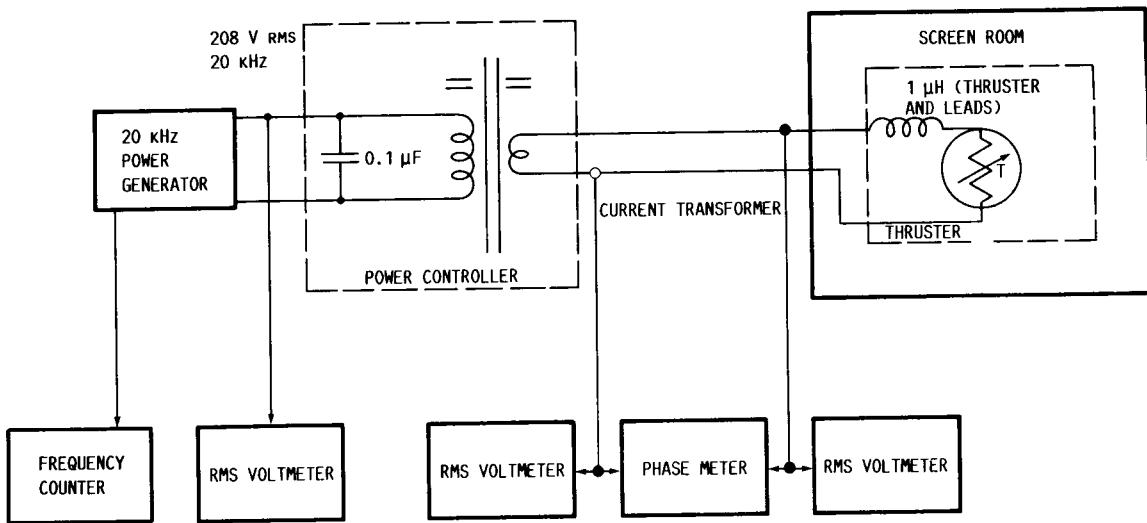


FIGURE 4. - SCHEMATIC OF EQUIPMENT SETUP.

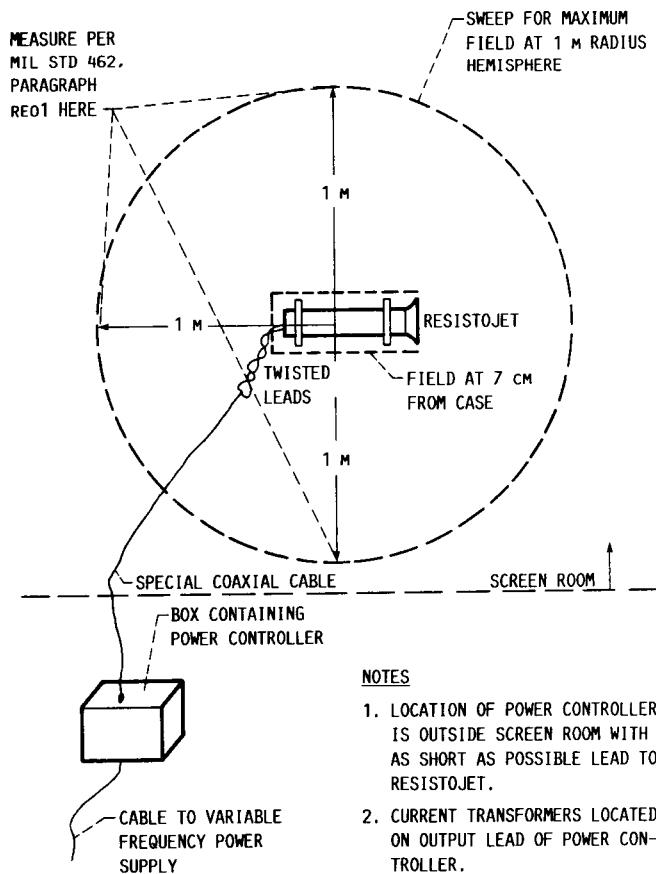


FIGURE 5. - EQUIPMENT LAYOUT AND MEASURING STATIONS.

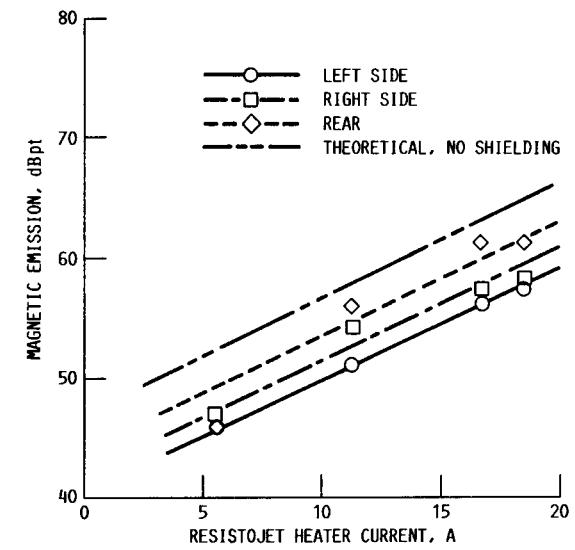


FIGURE 6. - MAGNETIC RADIATION AS A FUNCTION OF RESISTOJET HEATER CURRENT. (ONE METER DISTANCE, LEADS NOT SHIELDED.)

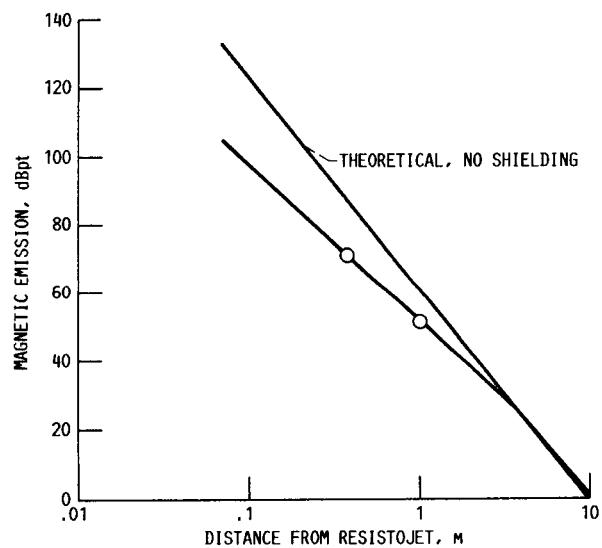


FIGURE 7. - MAGNETIC RADIATION AS A FUNCTION OF DISTANCE FOR A CURRENT OF 11.2 A.



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